Human-Building Interaction for Energy Conservation in Office Buildings

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ABSTRACT

Buildings are one of the major consumers of energy in the U.S. Both commercial and residential buildings account for about 42% of the national U.S. energy consumption. The majority of commercial buildings energy consumption is attributed to lighting (25%), space heating and cooling (25%), and ventilation (7%). Several research studies and industrial developments have focused on energy management based on maximum occupancy. However, fewer studies, with the objective of energy savings, have considered human preferences. This research focuses on office buildings' occupants' preferences and their contribution to the building energy conservation. Accordingly, occupants of selected university campus offices were asked to reduce lighting levels in their offices during work hours. Different types of information regarding their energy consumption were provided to the occupants. Email messages were used to communicate with the occupants. To monitor behavioral changes during the study, the test bed offices were equipped with wireless light sensors. The deployed light sensors were capable of detecting variations in light intensity, which was correlated with energy consumption. The impact of different types of information on occupant's energy related behavior is presented.

Keywords: Building energy, lighting system, occupant preferences, human-building interaction

Introduction

In the last two decades, global energy consumption and consequently CO_2 emissions have grown dramatically by 49% and 43%, respectively (IEA 2006; Perez-Lombarda et al. 2008). Current predictions show a global annual increasing trend of 2% in energy consumption and 1.8% in CO_2 emissions (IEA 2006; Perez-Lombarda et al.

2008). Fossil fuels are the source for about 81% of the primary energy consumption (IEA 2006). These energy resources are limited and are major contributors to the CO_2 emissions, which is correlated to global temperature rise (Dagobert G 2000). Therefore, ongoing global efforts have concentrated on reduction of energy consumption and CO_2 emissions.

Among all the consumers, buildings are one of the major players. In the U.S., both commercial and residential buildings account for about 42% of the annual energy consumption. Building sector consumes more than the industrial and transportation sectors. At the global level, it is also estimated that buildings consume 20% to 40% of the annual energy (Perez-Lombarda et al. 2008). Accordingly, many research efforts have been focused on sustainable practices to reduce energy consumption in buildings. The general vision for sustainable building is an intelligent building, which is responsive to the requirements of the occupants, environment and society by being functional and productive for occupants and sustainable in terms of energy consumption and CO_2 emissions (Clements-Croome 1997). To achieve this level of performance for the buildings, the interaction between building systems, processes and occupants are required. This interaction requires monitoring and control in the buildings by using the obtained information for improving the performance and quality of new and existing buildings (Clements-Croome 2011). Buildings are designed and constructed to perform based on standard set points, which are assumed to provide functionality and satisfaction for the majority of the occupants. These standard design conditions and set points are defined under controlled environmental conditions and use assumptions about buildings and occupants' behavior (Jazizadeh et al. 2011). However, research studies show that occupants are not always satisfied with the performance of the building systems and the predefined set points do not guarantee that occupant comfort and energy efficiency will be met (Corgnati et al. 2009; Wagner et al. 2007; Kwak et al. 2011). Moreover, occupants' behavior is an influential factor that affects building energy consumption and CO_2 footprint. Occupant's behavior is defined as a collection of factors such as activities, and preferences (Halfawy and Froese 2005). Dynamic occupant behavior and preferences are not taken into account in the operation of current building systems. In general, due to the complexity and diversity of the behavioral patterns, the influence of the occupants' behavior is considered only in simulation of typical occupant activities such as control of sun-shading devices (Halfawy and Froese 2005).

Occupants are a major factor in the energy consumption equation in buildings and arguably one of the most important factors in determining building's energy demand. In residential buildings, occupants are in charge of controlling building system performance and also responsible for the energy costs; so they have motivation to keep the balance between their energy related behaviors, their comfort preferences and their energy consumption. However, in commercial sector, the majority of buildings are managed centrally through Building Management Systems (BMS) and employers pay energy bills. Occupants are not involved and aware of the consequences of their behaviors. Accordingly, BMS should be capable of communicating with its occupants in sustainable commercial buildings, query their comfort levels and adjust the system settings based on their preferences. In some cases, occupant comfort may contradict with the goal of reduced building energy consumption, and modifying occupant's energy related behavior could increase building energy efficiency. This paper argues that BMS should have the capability of providing building occupants with energy related information and suggestions that could result in increased building energy efficiency. To test this possibility and to measure the success of providing energy related information in impacting occupant's energy related behaviors, this paper presents results from a test that focused on visual comfort and energy consumption related to lighting systems.

Occupant Behavior and Energy Consumption

In this study, occupants' preferences and habits that affect energy consumption are considered as occupants' behavior. As an example of an introduction of occupant behavior in the energy-comfort equation, Bourgeois, et al. (Bourgeois et al. 2006) have argued for an approach that predicts personal actions taken in response to physical conditions such as lighting levels, and hot/cold conditions by extrapolating from behavioral models derived from field studies. Though this approach looks promising, it can be challenging and as (Tanimoto and Hagishima 2010) pointed out it can result in gross overestimations of peak demand. This pattern of reasoning also does exist in thermal and adaptive comfort studies (Nicol and Humphreys 2009; Nicol and Humphreys 2002; Ole Fanger and Toftum 2002) as well as in studies examining how occupants react to a priori ambient factors (Reinhart and Voss 2003; Maniccia and Rutledge, B. and Rea, M.S. 1998; Morel, N. and Lindelo, D. 2006; Mahdavi 2008).

An alternative approach, which is adopted in this study, is to increase energy awareness. Energy literacy is the recognition of energy concepts (Darby 2006) and energy saving behaviors (DeWaters and Powers 2009). Energy literacy creates a tangible sense of end-user's energy consumption (DeWaters and Powers 2006). In order for building occupants to make informed choices related to energy, they need to understand its consumption as well as the potential consequences of overconsumption. Peschiera et al. (Peschiera et al. 2010) studied the effects of providing personal energy consumption to a group of students in dormitory units by providing different levels of information. In their study, one group was provided with their own energy consumption; another group was provided with building average energy consumption information; and the third group was provided with the peers' energy consumption. Providing peers' information and the social competition turned out to be the most effective strategy.

However, the past research has focused largely on household energy use, and little is known about interventions with employees at the office. In office buildings, occupants are not motivated to reduce their energy consumption. Moreover, due to occupants' preoccupation with their daily tasks, little attention is paid to energy related habits such as turning off appliances, which are not in use. In this study, occupants of office buildings are reminded about their behavior's impact on energy use by providing different levels of information; moreover, the impact of varying levels of information on energy related behavior is measured.

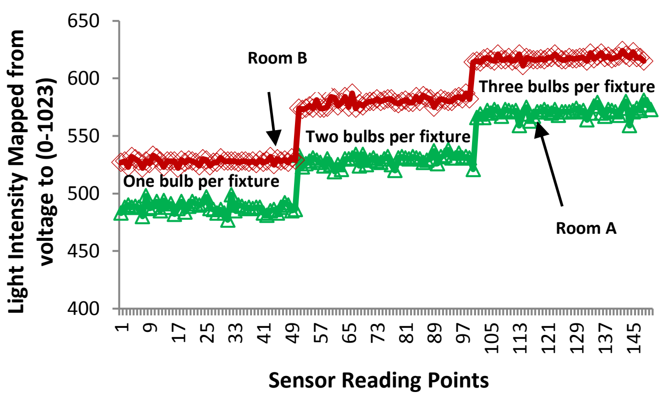
Experimental Set up

An experimental study was designed to investigate the effectiveness of conveying energy related information. Lighting systems are one of the best subjects for the purpose of this study due to their contribution to the overall building energy consumption and also due to the fact that lighting systems are accessible and controllable by occupants. Research studies show that occupants may be influenced by (1) antecedent (general) information such as practical ways for reducing energy-consumption disseminated through pamphlets or brochures and (2) consequence (feedback) information about their actions and/or knowledge of results (Wood and Newborough 2003). For this study, two groups of occupants were provided with different levels of information:

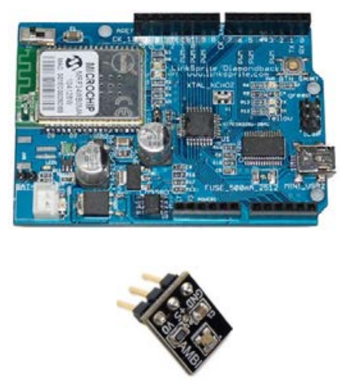
- Group I: Occupants in this group were asked to reduce their lighting levels in their offices and no supporting information was provided.
- Group II: Occupants in this group were asked to reduce their lighting level in their offices and information about the impact on energy consumption and environment was provided.

The occupants for this study were twenty-two university staff in seven buildings on the university campus divided into two groups of eleven individuals. Staff was chosen, as they tend to work in their offices for most of the time in the day. Visual observations of the target occupants' habits showed that all occupants keep their office lights on during working hours. Flexibility in adjusting the lighting level was the main criterion for selecting the rooms in this study. In campus buildings, typical light fixtures have three fluorescent light bulbs; therefore, for the fixtures that are equipped with double switches, the occupant can adjust lighting to four different levels - zero bulbs in use, 1 bulb in use, 2 bulbs in use and 3 bulbs in use. For this study, having windows or light fixtures with double switches were the main criteria for room selection. Considering the above-mentioned constraints, staff rooms were selected in seven different buildings.

With participants' agreement (under the IRB# UP-11-00329), the rooms were equipped with light sensors that are capable of detecting variation in the number of bulbs-in-use to measure occupant's compliance with the requests. These sensors communicated the light intensity readings through a wireless network to a database. Linksprite DiamondBack microcontrollers, equipped with a WiFi module and AMBI light intensity sensors, connected to an analogue pin of the microcontroller, were used. The AMBI light intensity sensor maps the voltage between 0 to 5 volts to a number between 0 and 1023, which is used as an indicator for light intensity. Figure.1-a shows the sensor readings for two rooms with different areas and different number of light fixtures. As it can be seen, the sensor is sensitive to changes in the number of bulbs-in-use for different room geometries. Since in this study the relative variation of the light intensity is important, no calibration process was carried out. The microcontroller and the AMBI light intensity sensor are shown in Figure.1-b. Visual observation of the rooms was also carried out as a contingency measure.



a) Sensitivity of the light sensor to the variations in light intensity



b) Linksprite Diamnodback Microcontroller and AMBI Light intensity sensor

Figure.1 Light intensity sensor components

The experiment for each group was carried out for three consecutive days and two reminder emails were sent to occupants on a daily basis. The first email was sent at 11 am and the second email was sent at 2 pm. The content of the email for each group was as follows:

- Group I: "By reducing (dimming) the lighting level in your office, you can reduce the total building energy consumption."

- Group II: "By reducing (dimming) the lighting level in your office, you can reduce the total building energy consumption. If you agree to reduce lighting level in your office, the annual collective energy savings at the building level can be up to 26,000 kWh on average, which is equivalent to a reduction of CO_2 emissions for 2.2 homes for one year and a reduction of greenhouse gas emissions that can be achieved by recycling 6.2 tons of waste."

In preparing the message for group II, it is assumed that on average in a building 100 rooms are going to respond and reduce the lighting (if the message is sent to all occupants). The next assumption is the reduction will be 1.024 KWh per day - equivalent of 4x32 watt bulbs (typical fluorescent bulbs are 32 watt) per room for 8 hours. In this way, about 103 KWh of savings in the building can be achieved. Considering there are 260 working days in a year, approximately 26,000 KWh of savings can be achieved per year per building. The reason for using energy information at the building level is to inform occupants that their collective contributions can result in considerable savings per year. Environmental impact of the savings was also added by converting KWh of savings. The experiment was conducted for two weeks in the fall of 2011. At the end of the experiment, a short exit survey was carried out. The questions were as follows:

What was the main reason for your actions?
If you agreed: (you can choose multiple answers) *a) I prefer using natural light* *b) Becoming more energy conscious was important for me* *c) Other: (please specify briefly)*
If you did not agree: (you can choose multiple answers) *a) I prefer using artificial light rather than natural* *b) I prefer using artificial light as well as natural* *c) There is insufficient natural light* *d) I prefer brighter lighting while working* *e) Other: (please briefly specify)*
Rate the usefulness of the message you have received. Rate it on a scale of 1 to 5, 1 being not helpful at all and 5 being extremely helpful

Results and Discussion

The outcome of the experiments has been presented in Table.1. As it could be seen in the second column of the table, the means of the average acceptance rate differ with about 40 percent between the two groups. The result of the t-test shows a p value less than 0.05. Accordingly, the difference between acceptance rate of group II comparing to the rate from group I is statistically significant. This difference proves that providing information intensive feedback is more effective in encouraging towards energy conservation than feedbacks without motivating information.

Table.1 Experiments results for acceptance rate and occupant rating

Group	Average Acceptance Rate (%)	Occupant Rating (1 to 5)
Group I	28.79	3.82
Group II	68.18	4.18
Mean Difference	39.39	0.36

On average almost 29% of the participants of Group I with standard deviation of 11.03% reduced the lighting level in their offices. In addition, about 68% of the participants in Group II with standard deviation of 9.65% reduced the lighting level in their offices. The standard deviation values also show that the data dispersion in each group was limited. On the other hand, although the occupants in group II rated that the feedback was more helpful, the difference between two groups' rating was not significant. The histogram of the exit survey rating results is as presented in Figure.2. On average, the rating of Group I in terms of usefulness of the message was 3.82 and the rating of Group II was 4.18.

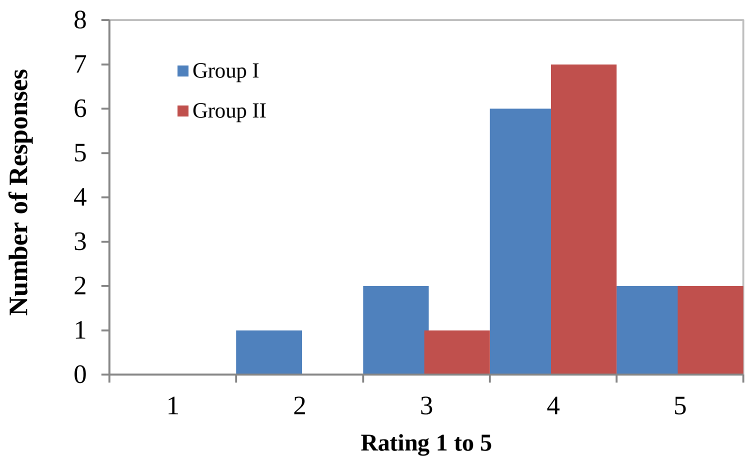


Figure.2 Histogram of the exit survey rating results

In Group II, nine of the participants mentioned the significant energy awareness as the reason for modifying their behavior, while, in Group I, only 4 participants pointed to energy awareness as their reason for modifying their behavior. In Group I, about 40% of the non-conformers stated that they were not fully convinced about the reason for reducing their lighting level. However, the remaining 60% stated that they prefer artificial lighting or brighter lighting while their working and they didn't mention any relationship between their behavior and the information level. In general, more than half of the participants in this study strongly believe that increasing energy awareness will be very helpful in encouraging occupants to think about energy consumption.

Since occupants in commercial buildings do not have direct financial motivation for energy conservation, this study shows that increasing the energy awareness by providing effective feedback from building performance to occupants could motivate occupants to adjust their behavior towards energy conservation.

Conclusion

In this study, the effect of providing reminders to occupants in order for them to modify their behavior towards energy efficiency in office buildings was investigated. Two different levels of information were provided through emails to two groups of eleven university staff. The results indicate that providing feedback with tangible information about the consequences of occupants' behavior is significantly more effective than providing simple reminders for behavior modifications. The experiment showed a 40% difference of acceptance rate between the test groups. This shows that in the office buildings, providing informative feedback can be used as an effective incentive for occupants to adopt energy efficient habits.

As part of the future work, a reminder system will be integrated with an intelligent negotiating agent as part of a multi agent simulation MAS solution (developed by authors). Also, the effect of normative information about how occupants' personal energy-conserving behaviors compare with others in the building will be tested.

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